



**US Army Corps
of Engineers**

Construction Engineering
Research Laboratories

USACERL Interim Report 97/23
December 1996

Development of Energy Screening Criteria for Use of Natural Gas-Fueled Technologies in the Department of Defense

Preliminary Investigation

by

William R. Taylor

The Department of Defense (DOD) is considering the application of natural gas (NG) technologies to decrease the life-cycle cost of delivering energy to its installations. To place the appropriate priority on NG technologies, estimates of the potential impact are needed. One method of estimating is to use the Renewables and Energy Efficiency Planning (REEP) program developed at the U.S. Army Construction Engineering Research Laboratories (USACERL). However, the current version of REEP evaluates only the most basic NG technologies. This study identifies additional advanced NG technologies, and will develop the necessary algorithms and incorporate them into the REEP program to analyze DOD energy and air emissions impacts.

This interim report briefly describes DOD natural gas consumption, efforts to reduce costs through centralized purchase of natural gas (by the Defense Fuel Supply Center), and DOD demonstration programs to encourage appropriate use of natural gas technologies. This initial stage of the study developed a preliminary list of NG technologies for possible inclusion into the REEP program, and also performed an initial REEP analysis using the existing gas technologies in REEP.

19970523 024

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED

DO NOT RETURN IT TO THE ORIGINATOR

USER EVALUATION OF REPORT

REFERENCE: USACERL Interim Report 97/23, *Development of Energy Screening Criteria for Use of Natural Gas-Fueled Technologies in DOD: Preliminary Investigation*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

4. What is your evaluation of this report in the following areas?

a. Presentation: _____

b. Completeness: _____

c. Easy to Understand: _____

d. Easy to Implement: _____

e. Adequate Reference Material: _____

f. Relates to Area of Interest: _____

g. Did the report meet your expectations? _____

h. Does the report raise unanswered questions? _____

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: _____

Telephone Number: _____

Organization Address: _____

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-TR-I
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	December 1996	Interim	
4. TITLE AND SUBTITLE Development of Energy Screening Criteria for Use of Natural Gas-Fueled Technologies in DOD: Preliminary Investigation			5. FUNDING NUMBERS MIPR DSAM 50060, dated 13 July 1995
6. AUTHOR(S) William R. Taylor			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005		8. PERFORMING ORGANIZATION REPORT NUMBER IR 97/23	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of the Assistant Secretary of Defense (Installations) ATTN: DASD(I) 400 Army Navy Drive, Rm 206 Arlington, VA 22202		10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Department of Defense (DOD) is considering the application of natural gas (NG) technologies to decrease the life-cycle cost of delivering energy to its installations. To place the appropriate priority on NG technologies, estimates of the potential impact are needed. One method of estimating is to use the Renewables and Energy Efficiency Planning (REEP) program developed at the U.S. Army Construction Engineering Research Laboratories (USACERL). However, the current version of REEP evaluates only the most basic NG technologies. This study identifies additional advanced NG technologies, and will develop the necessary algorithms and incorporate them into the REEP program to analyze DOD energy and air emissions impacts. This interim report briefly describes DOD natural gas consumption, efforts to reduce costs through centralized purchase of natural gas (by the Defense Fuel Supply Center), and DOD demonstration programs to encourage appropriate use of natural gas technologies. This initial stage of the study developed a preliminary list of NG technologies for possible inclusion into the REEP program, and also performed an initial REEP analysis using the existing gas technologies in REEP.			
14. SUBJECT TERMS energy efficient life-cycle costs natural gas			15. NUMBER OF PAGES 42
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

Foreword

This study was conducted for Office of the Assistant Secretary of Defense (Installations) under Military Interdepartmental Purchase Request (MIPR) No. DSAM 50060, dated 13 July 1995, "DOD Natural Gas Utilization: Development of Energy Technology Screening Criteria." The technical monitor was Millard Carr, DASD(I).

The work was performed by the Utilities Division (UL-U) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was William R. Taylor. Credit is owed to Bonnie Stillwagon, of the Defense Fuel Supply Center, Directorate of Alternative Fuels, Fort Belvoir, VA (DFSC-AD) for information on the Defense Fuel Supply Center Purchasing Program used in Chapter 2 of this report. Martin J. Savoie is Chief, CECER-UL-U; and John T. Bandy is Operations Chief, CECER-UL. Gary W. Schanche, CECER-UL, is the associated Technical Director. The USACERL technical editor was William J. Wolfe, Technical Resources.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

Contents

SF 298	1
Foreword	2
List of Tables	4
1 Introduction	5
Background	5
Objectives	5
Approach	5
Mode of Technology Transfer	6
Metric Conversion Factors	6
2 Energy Consumption	7
Consumption Background	7
Defense Fuel Supply Center Purchasing Program	7
3 Technology Opportunities	14
Family Housing Heating/Cooling	14
Building HVAC Systems	16
Utilities and Heating/Cooling Plants	17
Commercial Applications	22
Industrial/Process Applications	23
4 Demonstration Programs Status	25
Natural Gas Cooling Demonstration	25
Desiccant Cooling Demonstration	28
Fuel Cell Demonstration	28
5 Screening Analysis	31
Methodology	31
REEP Analysis Results	32
6 Summary and Conclusions	37

Distribution

List of Tables

Tables

1	DOD energy costs (× \$1000)	8
2	DOD energy consumption, FY94	9
3	REEP program groups of technologies	14
4	Emerging and state-of-the-art natural gas utilization technologies grouped by REEP categories	15
5	Current gas cooling demonstration sites	25
6	DOD gas cooling demonstrations	26
7	DOD dessicant cooling technology demonstrations	29
8	DOD fuel-cell technology demonstrations	30
9	Financial summary of ECOs (10 yr payback & 1.25 SIR)	33
10	Energy summary of ECOs	34
11	Pollution summary of ECOs	34
12	REEP simple analysis (noncompeting) of ECOs—cogen only	35

1 Introduction

Background

The Department of Defense (DOD) is considering the application of natural gas conversion technologies to decrease the life cycle cost of delivering energy to its installations. Recent developments in these technologies offer the potential to improve efficiency and reduce emissions at lower energy costs. Natural gas technologies such as low emissions burners, advanced gas turbines, and natural gas cooling systems are likely to become more important to the DOD. Identification of criteria for selection and application of these and other technologies is needed to compare their advantages and disadvantages.

Objectives

The objectives of this study are to develop criteria to quantify and compare energy and air emissions impacts of various natural gas technologies and various commercial and industrial heating and cooling technologies.

Approach

Current DOD natural gas consumption was reviewed. Ongoing DOD natural gas demonstrations (in fuel cells, desiccant systems, and gas cooling) were summarized. Previous research in identifying currently known, advanced gas technologies was used to enumerate potential gas technologies. The Renewables and Energy Efficiency Planning (REEP) software with its existing gas technology algorithms was used to preliminarily assess DOD energy and air emissions reduction potential. In cooperation with the Institute of Gas Technology, the latest advanced natural gas technologies were identified and summarized.

Mode of Technology Transfer

Information derived in this preliminary study will be used to:

1. Develop algorithms that will be incorporated into the REEP program to calculate energy and air emission impacts
2. Review and modify existing gas technologies in REEP
3. Enable the resultant REEP program to provide estimates of the potential impact of applying natural gas technologies within the DOD.

Metric Conversion Factors

The following metric conversion factors are provided for standard units of measure used throughout this report:

1 psi	=	6.89 kPa
1 ton (refrigeration)	=	3.516 kW
°F	=	(°C × 1.8) +32
1 hp hour	=	2.685 megajoule (MJ)

2 Energy Consumption

Consumption Background

Table 1 lists the fiscal year 1994 (FY94) DOD energy consumption. The FY94 total natural gas consumption for DOD is 93 million dekatherms. Natural gas supplied 32 percent of the total BBTus consumed by DOD. In comparison, electricity supplied 37 percent of the total BBTus consumed by DOD. From FY93 to FY94, natural gas consumption was reduced 7.4 percent while electricity consumption was reduced by only 1.9 percent. In comparison, energy consumption for fuel oil and coal dropped 7.6 and 12.7 percent, respectively, between FY93 and FY94.

Table 2 lists the FY94 DOD energy costs. The DOD total energy cost for FY94 was \$2.77 billion. Natural gas costs for FY94 were \$373 million; 13.5 percent of the DOD total. In comparison, electricity costs were \$1871 million (68 percent of the DOD total). Thus, while natural gas provided 32 percent of the BBTus, it required only 13.5 percent of the dollars expended for purchased energy. The FY94 average cost per unit of natural gas was \$4.02 per dekatherm or \$3.90 per MBtu. In comparison, the FY94 average cost for electricity was \$16.53 per MBtu.

Table 2 shows that 87 percent (81.3 of 93 million dekatherms) of DOD natural gas usage was for Buildings and Facilities; the remainder was for Industrial/Process applications. Typical natural gas usage in buildings and facilities is for heating, cooling, and hot water systems.

Defense Fuel Supply Center Purchasing Program

Background

Federal Energy Regulatory Commission (FERC) Orders 436 and 500, issued in the mid-1980s, deregulated the natural gas supplies and provided for open access to transportation on the interstate natural gas pipelines. Before this time, most natural gas supplies were available only from the local distribution companies (LDC) or interstate pipelines, many of which had entered into long-term "take or pay" natural gas supply contracts.

Table 1. DOD energy costs (* \$1000).

	Army	Navy	USAF	Others	Totals	Total FY93	%
Building & Facilities							
Electricity	\$541,171	\$383,598	\$526,743	211,810	\$1,663,322	\$1,775,372	-6.3%
Fuel Oil	86,779	60,604	77,167	19,195	243,745	253,705	-3.9%
Natural Gas	142,833	59,792	102,263	31,918	336,806	336,353	0.1%
LPG/Propane	8,194	2,339	2,357	675	13,565	15,433	-12.1%
Coal	29,864	1,485	23,492	3,431	58,272	46,180	26.2%
Purchased Steam	157,105	5,109	7,659	2,149	172,022	159,872	7.6%
Other	529	917	0	93	1,539	634	142.7%
Totals	\$966,475	\$513,844	\$739,681	269,271	\$2,489,271	\$2,587,549	-3.8%
Industrial /Process							
Electricity	\$3,749	\$121,186	\$83,194	0	\$208,129	\$226,470	-8.1%
Fuel Oil	102	14,171	666	0	14,939	17,119	-12.7%
Natural Gas	1,053	16,702	19,141	0	36,896	40,688	-9.3%
LPG/Propane	15	105	46	0	166	163	1.8%
Coal	6,047	4,507	0	0	10,554	11,749	-10.2%
Purchased Steam	0	4,697	1,921	0	6,618	11,575	-42.8%
Other	0	3,875	0	0	3,875	0	
Subtotal	\$10,966	\$165,243	\$104,968	0	\$281,177	\$307,764	-8.6%
Totals	\$977,441	\$679,087	\$844,649	269,271	\$2,770,448	\$2,895,313	-4.3%
FY 1994 Unit Costs							
Electricity (Mwh)	\$1,871,451	67.6%	33,005,914	56.70			
Fuel Oil (gal × 1000)	258,684	9.3%	381,363	678.31			
Natural Gas (cu ft × 1000)	373,702	13.5%	93,034,627	4.02			
LPG/Propane (gal × 1000)	13,731	0.5%	21,799	629.89			
Coal (tons)	68,826	2.5%	1,017,637	67.63			
Purchased Steam (Bbtus)	178,640	6.4%	11,988	14,901.57			
Other (BBtus)	5,414	0.2%	1,399	3,869.91			
Totals	\$2,770,448	100%					

Table 2. DOD energy consumption, FY94.

	Army	Navy	USAF	Others	Total FY94	Total FY93	% Change	FY94 BBtu	FY93 BBtu
Buildings & Facilities									
Electricity (MWh)	10,676,991	6,027,107	8,888,399	3,109,558	28,702,055	29,215,908	-1.8%	97,931	99,685
Fuel Oil (gal x 1000)	126,370	82,946	112,692	25,909	347,917	384,319	-9.5%	49,703	54,904
Natural Gas (cu ft x 1000)	33,900,400	14,122,383	28,587,737	4,707,383	81,317,903	88,071,063	-7.7%	83,839	90,801
LPG/Propane (gal x 1000)	13,610	2,417	3,259	2,185	21,471	23,883	-10.1%	2,050	2,281
Coal (tons)	321,853	35,444	356,285	66,316	779,898	902,103	-13.5%	19,185	22,192
Purchased Steam (BBtus)	9,877	761	1	333	10,972	11,151	-1.6%	10,972	11,151
Other (BBtus)	136	222	0	31	389	330	17.9%	389	330
							-6.1%	264,069	281,344
Industrial/ Process									
Electricity (MWh)	95,560	2,259,256	2,108,534	0	4,463,350	4,605,358	-3.1%	15,228	15,713
Fuel Oil (gal x 1000)	130	32,046	1,019	0	33,195	28,098	18.1%	4,742	4,014
Natural Gas (cu ft x 1000)	323,957	5,060,829	6,350,096	0	11,734,882	12,436,882	-5.6%	12,099	12,822
LPG/Propane (gal x 1000)	21	138	69	0	228	213	7.0%	22	20
Coal (tons)	158,539	79,495	0	0	238,034	263,889	-9.8%	5,856	6,491
Purchased Steam (BBtus)	0	966	1	0	967	2,220	-56.4%	967	2,220
Other (BBtus)	0	1,010	0	0	1,010	0		1,010	0
							-3.3%	39,924	41,280

Table 2. (Cont'd).

	Army	Navy	USAF	Others	Total FY94	Total FY93	% Change	FY94 BBtu	FY93 BBtu
Totals									
Electricity (MWh)	10,772,551	8,286,363	10,996,933	3,109,558	33,165,405	33,821,266	-1.9%	113,159	115,398
Fuel Oil (gal x 1000)	126,500	114,992	113,711	25,909	381,112	412,417	-7.6%	54,445	58,918
Natural Gas (cu ft x 1000)	34,224,357	19,183,212	34,937,833	4,707,383	93,052,785	100,507,945	-7.4%	95,938	103,623
LPG/Propane (gal x 1000)	13,631	2,555	3,328	2,185	21,699	24,096	-9.9%	2,072	2,301
Coal (tons)	480,392	114,939	356,285	66,316	1,017,932	1,165,992	-12.7%	25,041	28,683
Purchased Steam (BBtus)	9,877	1,727	2	333	11,939	13,371	-10.7%	11,939	13,371
Other (BBtus)	136	1,232	0	31	1,399	330		1,399	330
							-9.0%	20,195	22,192
FY94 Fuel Source %									
	BBtu	% of Total							
Electricity (MWh)	113,159	37.2%							
Fuel Oil (gal x 1000)	54,445	17.9%							
Natural Gas (cu ft x 1000)	95,938	31.6%							
LPG/Propane (gal x 1000)	2,072	0.7%							
Coal (tons)	25,041	8.2%							
Purchased Steam (BBtus)	11,939	3.9%							
Other (BBtus)	1,399	0.5%							
	303,993	100%							

As a result, gas sold to end users by the LDCs or interstate pipelines could be very expensive in relation to gas sold on the spot market. FERC Orders 436 and 500 opened the door for end users to have access to these lower cost spot market supplies. The military services began to contract independently for natural gas supplies for their individual installations. The lack of a formal structure to facilitate cooperation between the military services was a major impediment to the DOD's efforts in acquiring low cost natural gas supplies in this rapidly evolving industry. It soon became apparent that the ability to consolidate the natural gas requirements of all DOD installations located within each Local Distribution Company's service territory would enhance the buying power for these installations. A centralized natural gas acquisition within the DOD would also offer the opportunity for increased participation and potential savings opportunities for DOD installations. In 1989, the Defense Fuel Supply Center (DFSC) was given responsibility for this centralized effort.

Recent Regulatory Changes

The most recent regulatory changes with the greatest impact on the natural gas industry was the implementation of FERC Order 636 in October 1993, which required interstate natural gas pipelines to unbundle their natural gas supplies from the interstate transportation of natural gas. Before this order, interstate pipelines could give priority to the delivery of natural gas supplied and purchased for resale by the interstate pipeline company or its marketing affiliate. FERC Order 636 required pipelines to deliver natural gas supplies on a nondiscriminatory basis with no priority given to gas supplies shipped by the interstate pipeline marketing affiliate. This Order also allowed the holders of firm transportation to release unused firm capacity to replacement shippers either through prearranged deals or via a bidding process on the pipeline electronic bulletin boards. This capacity release mechanism has given shippers of both firm and interruptible natural gas supplies access to market driven, reasonably priced interstate pipeline transportation.

Most interstate natural gas pipelines are, and have been, fully subscribed by firm shippers, most of which are local distribution companies, electric utilities, and large commercial or industrial companies. As a result, prior to FERC Order 636, most DFSC direct supply natural gas was transported as interruptible, with contracts indexed to the maximum interruptible transportation rates of a pipeline serving the local distribution company franchised to serve the area in which an installation was located. These DFSC contracts are, of course, requirements type contracts, whereby the Government is obligated to purchase only the amount of the actual requirement and does not guarantee to purchase the total quantity indicated in the solicitation.

Contractors were required to pass along any transportation discounts they received from the interstate pipelines to the DFSC customers. Unfortunately, policing this requirement was almost impossible. Post Order 636 contracts require contractors to include interstate transportation costs in their transport adjustment factors, which has resulted in a reduction of transportation costs.

Under interruptible transportation, interstate pipeline curtailments could be verified with the interstate pipeline company. As a result, if a DFSC contractor was unable to deliver the total requirement, verification of curtailment of his interstate transportation (as required by the DFSC contract) was easily accomplished. Recall of firm released capacity, on the other hand, is much more difficult to verify. Also, firm released capacity has varying degrees of reliability, depending on the recall provisions of the contract between the releaser and the replacement shipper. To guarantee a percentage of reliability, most DFSC direct supply natural gas contracts now include a provision for limited interruptible transportation. The contract allows the contractor to use interruptible transportation, firm transportation, or firm released capacity (or a combination of all three) to deliver the natural gas requirement. However, the DFSC contract requires the contractor to deliver a certain percentage of the monthly ordered quantity. These percentages are generally based on the curtailment history provided by the interstate pipelines and the local distribution companies serving the area in which the installation is located.

Although the use of firm or firm released capacity has increased deliverability and reliability of interstate pipeline transportation at reduced costs, one disadvantage is that contractors can now acquire interstate pipeline capacity through agreements with third parties and, even though these agreements are supposed to be posted on the pipeline's electronic bulletin board, a "grey market" has arisen that is difficult, if not impossible, to track.

FERC Order 636 has given DFSC the opportunity to acquire interstate pipeline capacity as the shipper of record. Now DFSC can not only purchase the natural gas supplies, but also transport the gas under an agreement between DFSC and the interstate pipeline, store gas through an agreement with the pipeline, and balance the accounts of the customers served by the transportation agreement.

DFSC Program Participation

The first DFSC Direct Supply Natural Gas contracts were awarded in October 1990 for natural gas requirements to be delivered via interruptible transportation to 17 DOD installations in the central United States. Those contracts, as well as most subsequent contracts, were requirements type contracts with monthly economic

price adjustment provisions based on published market indicators that focus on the spot market price of natural gas.

In addition to DOD installations, the DFSC natural gas program has a large customer base of Federal Civilian facilities. Although most of the gas procured by DFSC for the DOD customers is for heating, cooling, and hot water purposes, it also contracts for natural gas supplies for testing and research and for commercial and industrial applications.

A small number of DOD installations use DFSC Direct Supply Natural Gas supplies as part of their cogeneration efforts. Additionally, DFSC contracted for gas supplies to be delivered to an electric utility company under an agreement with a DOD installation whereby the installation provided the natural gas required for the production of the electricity consumed at the installation.

Since the inception of the DFSC Direct Supply Natural Gas program, participation by DOD installations (as well as Federal Civilian installations) has continued to increase. At the end of FY95, 93 DOD installations located in CONUS and Alaska were participating in the program.

In FY94, the DFSC Direct Supply Natural Gas was 23,211,520 dekatherms; 25 percent of DOD's 93 million dekatherms of total consumption. For FY95, the total natural gas supplies purchased under DOD Direct Supply Natural Gas contracts was 31,280,466 dekatherms at an average cost to the installations of \$2.34 per dekatherm. In comparison, an equivalent amount of No. 2 fuel oil was \$4.45 (FY95 DFSC standard prices for bulk petroleum products) and an equivalent amount of No. 6 fuel oil was \$2.94 (FY95 DFSC standard prices for bulk petroleum products).

Comparing the DFSC average cost of \$2.34 per dekatherm (FY95) to the \$4.02 average cost for all natural gas consumed by DOD in FY94 (Table 1) indicates the possible savings. (DOD FY95 energy consumption data have not been obtained yet.) The \$1.68 per dekatherm difference in price suggests FY95 savings of approximately \$52 million (for the 31 million dekatherms of Direct Supply Natural Gas) purchased through DFSC. According to DFSC calculations, the total cumulative savings, from the inception of the DFSC Direct Supply Natural Gas program in October 1990 through July 1995, for all customers is \$99.6 million. Of this total, the savings for DOD installations is \$72.1 million.

3 Technology Opportunities

Numerous natural gas technologies with potential for application on DOD installations have emerged or are being developed. Some of the more common gas technologies have already been incorporated into the REEP program. The REEP program groups all technologies into the categories shown in Table 3, which also indicate proposed revisions to the categories used by REEP. The new and revised categories are proposed to accommodate the addition of new gas technologies. Table 4 shows a listing of emerging and state-of-the-art natural gas utilization technologies grouped according to the revised REEP categories with an indication whether each technology is currently in the REEP program. Technologies currently not in the REEP program will be considered, along with other gas technologies identified with assistance from the Institute of Gas Technology, for addition to REEP during the current USACERL study of DOD natural gas use. Technologies already in REEP will be reviewed and revised, as appropriate, during this current CERL effort. Each of the technologies listed are discussed briefly below.*

Family Housing Heating/Cooling

Engine-Driven Air-Conditioning Unit

Conventional air-conditioning units driven by gas engines offer high efficiency and reduce peak electric demand. The air-conditioning unit consists of a gas-fueled engine that drives a compressor. A gas-engine-driven unit can efficiently meet fluctuations in cooling demand by varying its speed. All ancillary

Table 3. REEP program groups of technologies.

Current REEP Technology Categories	Proposed New REEP Technology Categories
Electrical	Electrical
Envelope	Envelope
Heating/Cooling	Family Housing Heating/Cooling
	Building HVAC Systems
Lighting	Lighting
Miscellaneous	Miscellaneous
Renewables	Renewables
Utilities	Utilities & Heating/Cooling Plants
Water	Water
	Commercial Applications
	Industrial/Process Applications

* A more complete description of these technologies is available in: M.J. Savoie, P.M. Freeman, C.F. Blazek, and N.L. Potts, *Advanced Natural Gas Fuel Technologies for Military Installations*, Technical Report (TR) FE-94/24 /ADA290104 (U.S. Army Construction Engineering Research Laboratories [USACERL], September 1994).

components except the air-circulation fan are driven by the gas engine.

Residential Engine-Driven Gas Heat Pump

Heat pumps provide efficient cooling in the summer and can meet most of the heating load during winter months. The gas-engine heat pump replaces both the furnace and the AC unit. This technology is currently in REEP. Since it does replace both pieces of HVAC equipment, the gas engine-driven heat pump is only applied (in REEP) to installations that meet the Army's air-conditioning criteria. Although the current REEP algorithm for this technology does not address these capabilities, the gas-engine heat pump could conceivably heat water for domestic use and to power a backup generator during electrical outages.

High Efficiency Gas Furnaces for Family Housing

This technology is currently in REEP. Replacing the older furnaces in family housing with new high efficiency condensing units with pulse combustion could reduce fuel usage and costs up to 30 percent. Buildings best suited to conversion are those that have gas-fired furnaces.

Table 4. Emerging and state-of-the-art natural gas utilization technologies grouped by REEP categories.

<i>Category / Technology</i>	<i>Currently In Reep?</i>
<i>Family Housing Heating/cooling</i>	
Engine-Driven Air-Conditioning Unit	N
Residential Engine-Driven Gas Heat Pump	Y
High Efficiency Gas Furnaces for FH	Y
Nominal Efficiency Gas Furnaces for FH	Y
<i>Building Hvac Systems</i>	
Warm-Air Furnace	N
Desiccant Cooling	Y
Gas-Fired Heat Pumps	N
<i>Utilities & Heating/Cooling Plants</i>	
Cogen - Gas Turbine	Y
Cogen - Steam-Injected Gas Turbine	N
Cogen - Advanced Combined-cycle	N
Cogen - Recip. Engine	Y
Cogen - Peakshaving Twin-engine	N
Cogen - Phosphoric Acid Fuel Cells (Pafc)	Y
Cogen - Microgeneration Technology	N
Cogen - Tecogen Commercial Systems	N
Cyclonic Combustion Boiler	N
Gas Nominal Efficiency Boiler	Y
Gas High Efficiency Boiler (Pulse/modular)	Y
Pulsed-Combustion Steam Boiler	N
Triple-Effect Absorption Chiller	N
Gas Engine-Driven Chillers	Y
Gas Engine-Driven Compressors	Y
Gas-Engine Water Pump	Y
<i>Commercial Applications</i>	
Gas Booster Water Heater for Commercial Kitchens	N
Combination Steam/Convection Oven	N
Combination Broiler/Grididdle	N
Gas-Fired Rethermalizing Oven	N
High Performance Commercial Burner	N
<i>Industrial/Process Applications</i>	
Indirect-Fired Radiant Tube Burners	N
Radiant Tube Burners	N
Direct-Fired Radiant Burners	N
Pyrocore™ Radiant Tube Burner	N
Ultra-Low Emission Gas-Fired Combustor for Space Heaters	N
Ultra-Low NOx Industrial Hot Air Burner	N
Advanced Industrial Infrared Burner	N
Low-NOx Burners	N
Advanced Refinery Heater	N
Advanced Heat-Treating Ultracase™ Furnace	N
Advanced Gas-Fired Cement Furnace	N
Blast Furnace Natural Gas Injection	N
Gas-Fired Ion-Nitriding Vacuum Furnace	N
Gas-Fired Electric Arc Furnace Dust Incineration Process	N
Oxygen Enrichment for Furnaces	N
Gas-Fired Rapid Heating Furnace	N
Cullet Preheater	N
Glass Batch Preheater	N
Advanced Glass Melter	N
Mineral Wool Melter	N
Pulse Combustion Dryer	N
Convective Microwave Industrial Dryer	N
Dryers for Plastic Resins	N

Nominal Efficiency Gas Furnaces for Family Housing

Federal Standards have increased the minimum efficiency requirements for furnaces to 78 percent beginning 1 January 1992. Currently most furnace manufacturers bottom-of-the-line models are rated 80 to 82 percent efficient. This energy conservation opportunity (ECO) analyzes retrofitting older inefficient furnaces with nominal efficiency units. The nominal efficiency units cost significantly less than the high efficiency furnaces.

Building HVAC Systems

Warm-Air Furnace

Space-conditioning makes up a large percentage of total U.S. Army gas consumption. Many recent advances in burner technology and heat exchanger design could be applied to improve the efficiency of space-heating technology. With GRI support, Alzeta Corporation and Industrial Air Systems have developed a gas-fired furnace for heating large open spaces of commercial and industrial buildings such as warehouses, factories, churches, and schools. The furnace design includes the Alzeta Pyrocore™ radiant burner and fully condensing heat exchanger for high-efficiency operation.

Desiccant Cooling

Separate controls for humidity and cooling can provide increased comfort and efficiency. Desiccant systems can provide low cost, high efficiency cooling without the use of chlorofluorocarbons (CFCs). Advances in desiccant material have produced increases in coefficients of performance (COPs) for desiccant cooling systems. Due to minimal electrical requirements, desiccant systems also eliminate the peak electric demand associated with conventional air-conditioners. This technology is currently in REEP.

Desiccants are liquid or solid materials that soak up humidity and release water vapor when heated. For space conditioning applications, the desiccant is deposited on a "honeycomb" wheel between two air streams. The moisture from the indoor air is absorbed on one side and then released on the other side into the exhaust air. Sensible cooling is provided by incorporating evaporative coolers in the pass of the dry air or an externally refrigerated cold liquid.

Gas-Fired Heat Pumps

Gas heat pumps (GHPs) can provide both heating and cooling for space conditioning applications. GHPs can produce efficient residential heating using just one-fourth of the energy used by a high efficiency furnace. The GHP also provide cost effective cooling that reduces peak electric demand associated with conventional air-conditioning.

Utilities and Heating/Cooling Plants

Cogeneration—Gas Turbine

Cogeneration systems can be sized to meet the thermal load and provide the electricity to the on-base utility grid. The ability of gas turbine-generator sets to run efficiently and cleanly makes them suitable for base load power generation and increases electrical reliability at the installation. System are available in electrical capacities ranging from several hundred kWs to many MWs. This technology is currently in REEP. It is assumed for this application that the gas turbine cogeneration system will operate continuously and provide maximum power.

Cogeneration—Steam-Injected Gas Turbine Systems

General Electric (GE) Company, with support from the GRI, is developing a steam-injected gas (STIG) turbine cogeneration system capable of providing variable power output and steam production. A steam-injection system was added to the GE LM1600, a commercially available, easily maintained, and fuel-efficient gas turbine. The excess steam generated by the turbine exhaust heat can be used for process applications or recirculated into the turbine at 100 to 300 psi. Steam injection can reduce fuel consumption by up to 20 percent, or increase the electric output from 12 to 17.5 MW, depending on the electric demand. Steam injection increases the efficiency from 36 to 40 percent (lower heating value [LHV]). A gas-fueled turbine with steam injection also reduces emissions. The steam-injected LM1600 is commercially available.

In addition to the GE LM1600, the Allison Gas Turbine Division of General Motors offers a STIG cogeneration system based on their model 501-KH gas turbine. Another company, European Gas Turbines, offers STIGs reported to increase turbine output by up to 20 percent.

Cogeneration—Advanced Combined-Cycle System

Although very efficient for large plants, combined-cycle systems previously have not been cost-effective for plants under 20 MW because of the high capital cost and the relative inefficiency of small steam turbines. To solve this problem, Solar Turbines Inc., with support from GRI, has developed a 4.8 MW back-pressure steam turbine combined with an 8.6 MW gas turbine.

The advanced combined-cycle system can achieve an overall thermal efficiency of 75 percent. The high efficiency of the steam turbine is due to its high-temperature and high-pressure operation, advanced materials, and high rotational speed (30,000 revolutions per minute [rpm]). Variable thermal outputs (up to 109,000 lb of steam at 100 to 250 psi) and electrical outputs (8.6 to 13.4 MW) provide greater flexibility to accommodate fluctuating electric and thermal loads. An optional condensing steam turbine can be added to the system to convert the process steam to electricity for a total system output of 22 MW. The advanced boiler design also offers the capability of unattended operation and low emissions. The modular construction and simplification of the steam generator and steam turbine results in a low capital cost.

Cogeneration—Reciprocal Engine

Cogeneration systems can be sized to meet the thermal load and provide the electricity to the on-base utility grid. The ability of engine-generator sets to start quickly and run efficiently makes them ideal for peak shaving and to increase electrical reliability at the installation. This technology is currently in REEP. It is assumed for this application that the reciprocating engine cogeneration system will operate continuously and provide maximum power.

Cogeneration—Peakshaving Twin-Engine System

With support from GRI, Tecogen, Inc. has developed a peakshaving twin-engine cogeneration system. The system is designed to economically supply heat and electricity for buildings with a steady baseload energy demand, and to reduce the use of expensive utility peak electricity by doubling its speed and output during peak loads. The twin-engine system has a baseload capacity of 160 kW and a peak load capacity of 320 kW.

The system consists of two, 454 cu in. automotive-type, natural gas engines driven by a single 2-speed generator. The automotive engines are designed for high-speed operation, and are a fraction of the cost of industrial-grade engines. Engine life is extended by limiting the periods of peakshaving operation. A microprocessor control

system provides both on-site and remote operation capabilities and enables automatic switching between peakshaving and baseload operation.

Cogeneration—Phosphoric Acid Fuel Cells

Fuel cell technology displays great potential as a clean and efficient energy source that can use a variety of fuels. A fuel cell is an electrochemical device that converts fuel directly into electricity and heat.

The benefits of fuel cells include a very high electrical generation efficiency in comparison with other sources of power generation. Since fuel cell efficiency is relatively independent of load, this technology is useful for cogeneration and baseload power plants. In addition, the waste heat generated by fuel cells can be used for cogeneration applications. Fuel cells also produce low levels of emissions and noise, and modular construction of the fuel cell stacks make a range of sizes possible.

Although fuel cells can use a variety of fuels, natural gas is well suited for the technology. Natural gas contains few contaminants, requires minimal processing, and provides low energy costs. Of the various fuel cell types (classified on the basis of the type of electrolyte used), phosphoric acid fuel cells (PAFCs) are closest to commercialization. The PAFC has a relatively low operating temperature and is suitable for on-site applications to meet electrical demand and provide hot water and space heating.

Cogeneration—Microgeneration Technology

The initial costs of medium-sized (50 to 100 kW) packaged cogeneration systems have been reduced by high volume production and factory assembly. Since component, assembly, and maintenance costs do not scale down for smaller systems, the first cost of units less than 50 kW have remained too high for commercial success. Sponsored by GRI and Southern California Gas Company, Tecogen, Inc. is developing advanced control, heat recovery, and packaging technologies for cost-effective microgeneration systems with 81 percent efficiency and high reliability. These concepts will be designed for light commercial applications of various sizes.

Cogeneration—Tecogen Commercial Systems

Tecogen has developed a 600 kW unit that produces low-pressure steam and variable amounts of electricity. Waste heat from the engine's cooling jacket is compressed to 85 to 125 psi gage (psig) steam. This system offers added flexibility by controlling the use of the compressor to provide the option of low pressure steam or

additional electricity as needed. For example, during winter months, the system can provide low pressure steam for space heating and hot water. During the summer, the unit can generate the maximum electricity to offset peak utility charges and the low pressure steam can be used for hot water and absorption cooling.

Cyclonic Combustion Boiler

Cyclonic combustion takes place in a cylindrical combustion chamber. Natural gas and air are injected tangentially at high speed producing a swirling combustion flow pattern. This flow internally recirculates partially combusted hot gases, which intensifies and further stabilizes combustion. It also improves temperature and combustion uniformity, and reduces peak flame temperature to minimize NOx formation.

Gas Nominal Efficiency Boiler

The replacement of older, inefficient, gas-fired boilers can save a significant portion of the yearly gas heating costs. This technology is currently in REEP. It is assumed that the buildings best suited for conversion are those that have gas-fired hot water boilers in the size range of 0.5 to 1.5 MBtu/hr.

Gas High-Efficiency Boiler

Replacing the older boilers with new high efficiency modular boilers could reduce fuel usage and costs up to 50 percent. This technology is currently in REEP. Buildings best suited to conversion are those that have gas-fired hot water boilers in the size range of 0.5 to 1.5 MBtu/hr. The typical plant is replaced by two high efficiency boilers with a rating of 40 percent of the original capacity.

Pulsed-Combustion Steam Boiler

A pulse combustor consists of a combustion chamber, valves, and exhaust pipes designed to regulate the combustion process by the action of combustion-generated waves. Once started, the pulse combustor is self-igniting and vents combustion products without needing a blower or a flue. Pulsed-combustion boilers have many advantages compared to boilers using power or atmospheric burners. The boiler operates with lean-fuel conditions, produces relatively low levels of NOX emissions, and generates very high heat transfer rates. The high heat transfer of pulse combustion requires less heat exchanger surface while improving efficiency to 85 percent. Pulse combustion also permits modulated operation without a drop in efficiency. Due to its self-venting feature, combustion-air fans or expensive stack

systems are not needed. Pulse combustion can be used in low- and high-pressure steam boilers. This technology is currently in REEP.

Triple-Effect Absorption Chiller

Absorption cooling systems are heat-operated refrigeration systems that use pumps, heat exchangers, and pressure vessels in the place of the compressor used in conventional mechanical refrigeration. Absorption chillers recover low-grade industrial waste heat from cogeneration or process steam and produce chilled water.

Gas industry researchers and the Trane Co. are developing a triple-effect absorption chiller based on the concept of a high temperature topping cycle followed by a low temperature bottoming cycle. The triple-effect chiller consists of a conventional single effect chiller combined with a smaller, higher temperature chiller. The high temperature topping cycle is fueled by natural gas combustion. Heat rejected from the topping cycle is used as the energy source for the bottoming cycle. The triple-effect technology is expected to achieve a coefficient of performance (COP) of 1.5, and an increase in efficiency of 50 percent over state-of-the-art double-effect absorption chillers.

Gas Engine-Driven Chillers

With support from GRI, Tecogen has developed a high efficiency, 150-ton, gas engine-driven chiller. The chiller is based on the automotive engine, which is durable but less expensive than an industrial engine due to high volume production. Carrier Corporation is jointly marketing it with Tecogen. The engine-driven chiller is expected to reduce customer cost by 30 percent or more.

Gas Engine-Driven Compressors

An increasing variety of tools and machinery are being run on compressed air. Although most industrial compressed air systems are driven by electric motors, gas-fueled engines provide a low cost, high-efficiency alternative.

Although electric rates vary from region to region, the energy cost of operating a gas-fueled engine is usually much lower than the cost of operating an electric motor. In addition, the variable speed capability of gas engines allows them to operate efficiently at partial load. Electric compressor motors, on the other hand, are constant-speed devices without the flexibility of gas engines. The output capacity of electric compressors is controlled by throttling (restricting) the compressor inlet, which

inherently reduces efficiency. Also, gas-powered compressors reduce costs by eliminating peak electric demand charges and freeing up electric capacity.

Gas-Engine Water Pump

Municipal water wells and pumping systems typically use electric motors ranging from 50 to several hundred hp. It is assumed in REEP that these pumps operate on an "as required" basis. This can add significantly to an installation's peak electrical demand. Typically only a portion of these pumps would be converted to natural gas engine-driven prime movers. Additional controls would provide an operating sequence such that, during the on-peak period, the engine-driven pumps are the lead system while the electric motor pumps lag. Engine-driven pumping systems have been used successfully for crop irrigation for many years and are beginning to be used for municipal water-pumping systems.

Commercial Applications

Gas Booster Water Heater for Commercial Kitchens

Booster heaters are used in many restaurants and institutional kitchens to raise the temperature of the hot water—usually set at 140 to 180 °F for a final sanitizing rinse. Although electric booster water heaters are commonly selected for their small size, they produce high operating costs. The American Gas Association Laboratories and Raypak, Inc., have developed an under the counter gas-fired booster water heater for GRI at the Gas Appliance Technology Center.

Combination Steam/Convection Oven

Combination steam and convection ovens are used for a variety of institutional cooking applications, including baking, roasting, moist roasting, and steaming. Electric combination ovens use resistance heaters that offer limited capabilities and a tendency for early failure caused by scale deposits and overheating.

Combination Broiler/Griddle

To improve cooking efficiency and decrease cooking time, a griddle was designed with an electric broiler to broil food from above while frying it on the griddle. The disadvantages of the electric broiler are its fragility, the high replacement cost of the quartz heating elements, and the difficulty cleaning the unit. A gas-fired infrared broiler section has been developed for installation on top of gas-fired griddles.

Gas-Fired Rethermalizing Oven

In large volume food preparation, food typically is cooked in a conventional oven, chilled quickly to avoid bacteria growth, then "rethermalized" (reheated) several days later for serving. This process saves labor costs since skilled cooks can prepare food in advance. Conventional rethermalizing ovens are usually electric, a technology that involves high energy costs and the expense of replacing the electric resistance heaters. A gas-fired oven that can be used for rethermalizing as well as conventional convection cooking has been developed.

High Performance Commercial Burner

A powered burner for commercial open-top ranges has been developed. The powered burner provides the same usable output as conventional burners, but at a reduced input. This results in lower operating costs and better performance.

Industrial/Process Applications

A number of industrial/process natural gas applications have been identified from previous research. To determine whether these technologies should be in the REEP program, it will be necessary to assess the applicability of each of these technologies to DOD facilities. A preliminary list of industrial/process technologies follows:

- Indirect-Fired Radiant Tube Burners
- Radiant Tube Burners
- Direct-Fired Radiant Burners
- Pyrocore™ Radiant Tube Burner
- Ultra-Low NO_x Industrial Hot Air Burner
- Advanced Industrial Infrared Burner
- Advanced Refinery Heater
- Advanced Heat-Treating Ultracase™ Furnace
- Advanced Gas-Fired Cement Furnace
- Blast Furnace Natural Gas Injection
- Gas-Fired Ion-Nitriding Vacuum Furnace
- Gas-Fired Electric Arc Furnace Dust Incineration Process
- Oxygen Enrichment for Furnaces
- Gas-Fired Rapid Heating Furnace
- Cullet Preheater
- Glass Batch Preheater
- Advanced Glass Melter

- Mineral Wool Melter
- Pulse Combustion Dryer
- Convective Microwave Industrial Dryer
- Dryers for Plastic Resins.

4 Demonstration Programs Status

Several of the natural gas technologies have gained sufficient public attention to receive congressional funding to demonstrate the technology at military installations. USACERL is currently executing DOD demonstrations of natural gas cooling, desiccant cooling, and fuel cells. For each of these demonstration programs, the currently selected sites are indicated with a very brief indication of status.

Natural Gas Cooling Demonstration

Background

The FY93 Defense Appropriations Act provided \$6 million of equipment procurement funds to the DOD for "natural gas chillers for the air-conditioning of Department of Defense facilities." The FY94 Defense Budget also includes \$16,750,000 to continue this program. Strategic Environmental Research and Development Program (SERDP) funding (FY94-95) helped support program activities. The program is providing field demonstrations of natural gas cooling technologies and evaluating their overall potential within the DOD.

Demonstration Site Status

A number of demonstration sites have been selected and are at various stages of completion. Table 5 lists the number of sites at various stages of the demonstration process. Data collection is presently occurring at several of the operational sites. Table 6 lists current gas cooling demonstration sites. For each site, the retrofit equipment is indicated along with the current status of the project.

Table 5. Current gas cooling demonstration sites.

Activity	Number of Sites
Evaluated	20
Designed	14
Installed	6
Operational	5

Table 6. DOD gas cooling demonstrations.

Location	Facility	Existing Equipment	Retrofit Equipment	Technical & Economic Factors	Status as of Jan96
Fort Eustis, VA	Bldg 2716	100 ton elec chiller	Gas engine-driven chiller (comparable size)		Awaiting definitive plans from Fort Eustis personnel
Fort Hamilton, NY	Barracks bldg	1 - 50 ton chiller & 1-60 ton chiller	1-125 ton engine-driven chiller	Rebate offered by utility.	
Fort Hamilton, NY	Day Care bldg	air-cooled 25 ton, DX rooftop unit	Gas engine-driven chiller	Retrofit will lower annual operating costs.	Designs are complete. Contracting documents under development.
Fort Huachuca, AZ	Hospital	2-128 ton elec. chillers (25 yrs old, CFC base)	2-150 ton, 2-stage, steam-fired, absorption chillers		Existing equipment lacked sufficient capacity. Necessary repairs to facility and aux. equipment performed with this project. Simple payback less than 3 years.
Fort Jackson, SC	Central plant	1-400 ton CFC-111 chiller, 1-750 ton single stage absorption chiller	2-700 ton gas-driven chillers	Existing equipment lacked capacity. Options were studied. Electric service insufficient for elec. chillers. Utility incentive for gas. Reclaimed exhaust heat for DHW; 4-year payback	System installed.
Fort Riley, KS	Irwin Medical Center	3-200 ton steam-driven centrifugal chillers (old, CFC based), (2-485 ton chillers -not replaced)	2-350 ton HCFC-22 gas engine-driven chillers	Options studied. Electric service capacity inadequate. Heat recovery for DHW. Data monitoring system included; 9-year payback.	System installed.
Naval Air Station Willow Grove, PA			1-25 ton engine-driven split system chiller, 1-80 ton engine driven chiller	Will reduce CFC use. Est. \$18K per year savings.	Completed in 1993 by Willow Grove.
Naval Air Station Willow Grove, PA	Bldg 180 - AIMD	Centrifugal CFC-111 chiller	1-80 ton direct-fired double-effect absorption chiller, 1-30,000 cfm two-wheel desiccant system	High electric demand rates. NAS Willow Grove is Navy showcase site for natural gas cooling technologies.	
Naval Training Center, Great Lakes, IL	Hospital	2-175 ton single-effect steam absorption chillers	2-175 ton natural gas direct-fired double-effect absorption chillers	Some winter cooling required. NFESC installing monitoring equipment; 4-year payback. No CFC reduction.	Equipment installation complete in Nov95.
Naval Medical Center, Bethesda, MD	Hospital	2-500 ton steam-fired absorption chillers	1-1000 ton dual fuel (NG/Oil) direct-fired double-effect absorption chiller	New chiller will run at maximum during peak demand. Connected to existing cooling tower used for all chillers (7220 tons capacity).	Chiller has been installed and expected on-line by late Jan96.

Table 6. (Cont'd).

Location	Facility	Existing Equipment	Retrofit Equipment	Technical & Economic Factors	Status as of Jan 96
Marine Corps Air Station, Yuma, AZ	Barracks	1-283 ton centrifugal CFC-11 chiller (25 yrs old) & cooling tower	1-300 ton direct-fired double-effect absorption chiller & cooling tower	Existing unit lacked capacity and required high maintenance. Reduction in CFC use; 9-year payback.	Chiller expected to be installed and fully operational by late Jan 96.
Submarine Base, New London, CT	Bldg 488 BOQ	1-175 ton CFC-11 centrifugal chiller & cooling tower (13 yr old)	1-175 ton direct-fired double-effect absorption chiller & cooling tower	High electric demand charge. Estimated \$16K/yr savings. Nearly a 4-year payback.	Design complete. Funds for construction sent to New London in Nov 95.
Naval Training Center (NTC), Great Lakes, IL	Bldg 1405, Administration	1-400 ton centrifugal CFC-12 chiller	1-400 ton direct-fired double-effect absorption chiller	Utility rebate. Estimated savings is \$8.5K per yr; 6-year payback.	Design is complete. Funds sent to NTC in Nov 95. Expect construction contract award by late Jan 96.
Fleet Combat Training Center, Damneck, VA	Bldg 543, Naval Guided Missile School	1-260 ton centrifugal CFC-11 chiller	1-210 ton direct-fired double-effect absorption chiller	Previous bldg and HVAC retrofits have reduce the cooling capacity requirement. Utility rebate. \$5.8K/yr savings; 7-year payback.	Design is complete. Awaiting award of construction contract.
Naval Education and Training Center, Newport, RI	Bldg 95, Officer's Club	1-120 ton centrifugal CFC-12 chiller (11 yrs old)	1-120 ton direct-fired double-effect absorption chiller & cooling tower	Eleven month demand ratchet. Utility rebate. Estimated savings \$10K/yr; 3-year payback.	Design is complete. Awaiting construction.
Naval Air Station, Miramar, CA	Bldg 515, Mnt. Training Facility	Rented chiller this past year (\$6K/month)	1-150 ton natural gas absorption chiller & cooling tower.	Estimated savings \$8K/yr; 8-year payback.	Chiller and ancillary equipment received. Awaiting completion of construction.
Columbus Air Force Base, OH	T34/T38 Training Facility	2-329 ton CFC-12 electric driven chillers	1-250 ton gas engine-driven chiller	One of the existing chillers will remain. High demand charge. Payback is 3 years.	Awaiting Air Force review of project.
Davis-Monthan Air Force Base, AZ		1-400 ton gas engine driven chiller, 1-400 ton electric driven chiller	1-350 ton gas engine driven chiller (to replace elec. chiller)	Approx. a 5-year payback.	Base is pursuing FEMP funds to complete project. Demo is on-hold.
Tinker AFB, OK	Bldg 3001	3-1500 ton steam turbine driven chillers (5 additional existing chillers are not being replaced)	3-1000 ton direct-fired double-effect absorption chillers	Replacement intentionally reduces overall system capacity.	To occur in FY97.
Warren-Robins Air Force Base, GA	Central facilities		2-1500 ton gas engine driven chillers	Base will fund most facility modifications.	Design to begin 2nd quarter FY96. Construction expected in FY97.
Wright-Patterson Air Force Base, OH	Hospital	3-electric chillers (only two can operate at a time due to limited electrical capacity.)	Hybrid electric and gas engine driven system		Design to begin in 2nd quarter FY96.

Desiccant Cooling Demonstration

The FY94 Defense Appropriations "Research, Development, Test and Evaluation, Army" directed that \$200,000 be appropriated for a natural gas-fired desiccant cooling demonstration. The FY95 Defense Appropriations, "Operations and Maintenance, Defense-Wide" directed that \$2.5 million of the Federal Energy Management Program budget be "reserved for energy improvements involving the two-wheel, super high efficiency desiccant dehumidification and cooling systems."

Table 7 lists 14 sites that have been selected or that are being evaluated to receive a desiccant system to supplement the existing cooling system. Nine of the 14 sites are in the design or construction stage of the process.

Fuel Cell Demonstration

Background

The FY93 Defense Appropriations Act provided \$6 million per service for procurement of "natural gas fuel cells currently in production in the United States." The FY94 Defense Appropriations Act provided \$6.25 million per service for procurement of fuel cells. These funds have been used to purchase "turnkey packages," which include installation and initial maintenance of the fuel cell equipment. Other demonstration activities such as site evaluations, contract administration, and performance monitoring have been supported by the SERDP program and by the Office of the Assistant Secretary of Defense.

Demonstration Site Status

From the FY93 appropriation, fuel cell power plants have been installed at 12 DOD locations. These FY93 sites are listed in Table 8 along with the type of facility served. It is expected that the FY94 appropriation will result in the purchase and installation of approximately 21 additional fuel cell power plants. (Between FY93 and FY94, the price per fuel cell charged by the manufacturer has been lowered significantly; allowing more units to be purchased.) Sites for placement of the FY94 appropriated fuel cells will be determined in FY96.

Table 7. DOD dessicant cooling technology demonstrations.

Location	Facility	Desiccant size (cfm)	Comments	Status as of Jan96
NAS Willow Grove, PA	AIMD	5000	Has one of highest electrical rates in U.S.; conversion to gas technologies is very beneficial	Design complete
NPWC, Pensacola, FL	Environmental	4000	High humidity region at Gulf of Mexico coast	Under construction
NADEP Jacksonville, FL	Avionics Center	2x20000	Specific humidity requirements in electronics laboratories	Being designed
Columbus AFB, OH	Photographic Lab.		Photographic materials easily ruined by high humidity; quality of product altered significantly	Evaluation ongoing
Columbus AFB, OH	Avionics		Specific humidity tolerance range must be maintained in laboratory	Evaluation ongoing
Keesler AFB, MS	Bowling Alley	2x20000	Condensation on lanes causes problems	Contracted, awaiting construction
MacDill AFB, FL	Hospital	18000	Specific humidity control needed in surgical areas	Under construction
Tyndall AFB, FL	PMEL Evaluation	4000	Tight humidity control required in calibration laboratory	Draft report Received
Fort Myer, VA	Barracks/O-Club	3x4000	Occupant comfort and safety enhanced	Being designed
Fort Benning, GA	Commissary	2x8000	Frost on display cases decreases sales	Contracted, awaiting construction
Fort Benning, GA	Museum	8000 & 20000	Sensitive historical items can be damaged by excessive humidity	Contracted, awaiting construction
Fort Benning, GA	Operating unit	4000	Specific humidity control needed in surgical areas	Contracted, awaiting construction
Fort Campbell, KY	Museum		Sensitive historical items can be damaged by excessive humidity	Evaluation ongoing
West Point, NY	Ice Arena		Fog forms in arena, ductwork rusting, mold formation in crevices due to condensation	Evaluation ongoing

Table 8. DOD fuel-cell technology demonstrations.

Location	Facility	Application	Estimated Annual Savings	Status as of Jan 1996
Soldier Systems Command, Natick, MA	Central heat plant	Heat boiler make-up water and condensate return	\$58,000	Operational as of 9 Feb 1995
Naval Education Training Center, Newport, RI	Central heat plant	Heat boiler make-up water	\$103,000	Operational as of 10 Feb 1995
934th Tactical Air Group, Minneapolis, MN	Central heat plant	Heat boiler make-up water and condensate	\$35,000	Operational as of 16 Feb 1995
Twenty-nine Palms Marine Corps Base, CA	Hospital	DHW	\$57,000	Operational as of 23 Jun 1995
Kirtland AFB, NM	Central heat plant	Heat boiler make-up water	\$58,000	Operational as of 17 Sep 1995
Fort Eustis, VA	Recreation facility	Heat swimming pool	\$35,000	Operational as of 21 Sep 1995
Nellis AFB, NV	Barracks complex	Heat DHW and heat pump recirculation	\$38,000	Operational as of 27 Sep 1995
Picatinny Arsenal, NJ	Boiler plant	Heat Boiler Make-up Water	\$95,000	Operational as of 26 Oct 1995
West Point, NY	Central power plant	Heat boiler make-up water	\$37,000	Operational as of 21 Nov 1995
Camp Pendleton, CA	Hospital	Heat DHW	\$96,000	Operational as of 29 Oct 1995
Vandenberg AFB, CA	Launch operations control center	Heat DHW	\$32,000	Was put in operation. Has been down while attempts are being made to resolve problems related to electrical systems interactions
U.S. Naval Academy, Annapolis, MD	Galley	DHW/steam	To be determined	Awaiting design. (Previously scheduled for the FY94 program. Late change in site at request of the Navy.)

5 Screening Analysis

Methodology

One method for evaluating the potential impact of various natural gas technologies is to use REEP software developed at USACERL. The REEP software performs a generalized energy/financial/pollution analysis for energy saving technologies at DOD installations in the continental United States. Facility data, weather data, utility rates, and electrical generation mix are contained in installation database files. An initial analysis applies algorithms for each technology to the various data to produce energy savings estimates. These estimates are then used in an economic analysis that considers regional pricing and life-cycle factors. The economic analysis is based on the DOD's Energy Conservation Investment Program (ECIP) standards. The economic results are then filtered through user-set minimum requirements. To address the possibility of competing technologies, the analyst can select competition criteria (like simple payback) and run a separate analysis to exclude competing technologies that are less attractive. Pollution abatement estimates are then calculated based on the energy savings and regional electrical generation mix. Finally, all of the results are totaled across the selected installations.

For this analysis, a technology was considered economically viable if it had a simple payback of 10 years or less, and a savings to investment ratio (SIR) 1.25 or greater. REEP offers a wide variety of energy conservation technologies. For this analysis, only the natural gas technologies were selected. The natural gas technologies currently found in REEP (and described in Chapter 3 of this report) are:

- Cogeneration-Fuel cell
- Family Housing (FH) High Efficiency Gas Furnace
- Cogeneration-Gas Turbine
- FH Nominal Efficiency Gas Furnace
- Cogeneration-Reciprocating Engine
- FH Gas Engine-Driven Heat Pump
- Direct-Fired NG Chillers (5 to 50 tons)
- Desiccant Cooling
- Direct-Fired NG Chillers (50 to 100 tons)
- Gas High Efficiency Boilers

- Direct-Fired NG Chillers (>100 tons)
- Gas Nominal Efficiency Boilers
- Gas-Engine Chillers (5 to 50 tons)
- Gas-Engine Air Compressors
- Gas-Engine Chillers (50 to 100 tons)
- Gas-Engine Water Pump
- Gas-Engine Chillers (>100 tons).

Note that some of these technologies compete. Each “Cogeneration” technology competes with other cogeneration technologies; direct-fired chillers compete with gas-engine chillers.

The analysis for this interim report used the gas technologies currently available in REEP listed above. The major focus of this natural gas utilization study is to identify additional natural gas technologies and develop the algorithms to be included in the REEP software. The final report of this effort will include REEP analysis incorporating the newly developed natural gas REEP algorithms. The advanced gas technologies listed in Chapter 3 are some of the technologies being considered. Along with the newly developed algorithms for advanced gas technologies, the REEP algorithms for the existing gas technologies will be reviewed and modified as needed.

REEP Analysis Results

As required by REEP, initially a Simple Analysis (no screening or eliminating competing technologies) was performed. All DOD installations were included. Only the gas-related ECOs (as listed above) were selected. Following the Simple Analysis, the Financial, Resource, and Pollution analysis were run and results are shown in Tables 9, 10, and 11, respectively. In the tables, the Cogeneration technologies are broken out with a separate subtotal. The Cogeneration technologies are capable of greatly increasing the totals to levels that may not be realistic, given the real world practical limits imposed by the need to reduce physical plant ownership (privatization) and associated maintenance despite the potential savings, or other policy and financial limitations. The Cogeneration subtotals in Tables 8, 9, and 10 are “competed” results; only the most economical choice is listed as an opportunity for sites where more than one type of cogeneration was applicable.

Table 9. Financial summary of ECOs (10 yr payback & 1.25 SIR).

	No. of Installations	No. of Opportunities	Initial Cost (\$)	Total Savings (\$/Yr)	Simple Payback (Years)	SIR Ratio	Adjusted Internal Rate of Retrn
FH Heating/Cooling							
1 FH High Efficiency Gas Furnace	0	0	\$0	\$0	0	0	0
2 FH Nominal Efficiency Gas Furn	45	24175	\$19,079,631	\$2,537,176	7.52	2.64	9.2%
3 FH Gas Engine Drvn HP	16	13055	\$81,252,313	\$11,219,414	7.24	2.13	8.0%
Bldg HVAC							
4 Dessimant Cooling	22	2730	\$60,696,882	\$11,068,129	5.48	2.29	8.4%
Utilities/Central Plants							
5 Gas High Efficiency Boilers	104	7457	\$55,271,877	\$8,248,982	6.7	2.23	9.7%
6 Gas Nominal Efficiency Boilers	1	1	\$4,436	\$470	9.44	1.68	7.7%
7 DF NG Chillers > 100 Tons	0	0	\$0	\$0	0	0	0.0%
8 Gas-Engine Chillers > 100 Tons	26	425	\$68,448,756	\$11,997,048	5.71	2.38	8.6%
9 DF NG Chillers 50-100 Tons	1	10	\$592,704	\$61,219	9.68	1.6	6.5%
10 Gas-Engine Chillers 50-100 Tons	31	703	\$37,697,985	\$7,436,149	5.07	2.77	9.4%
11 DF NG Chillers 5-50 Tons	0	0	\$0	\$0	0	0	0.0%
12 Gas Engine Chillers 5-50 Tons	14	545	\$14,240,578	\$2,885,607	4.94	2.93	9.7%
13 Gas-Engine Water Pump	74	667	\$53,252,631	\$10,784,455	4.94	2.12	8.0%
14 Gas-Engine Water Compressors	7	7	\$481,824	\$100,752	4.78	2.82	9.5%
Subtotal (1 thru 14)							
15 Cogen-Fuel Cell	0	0	\$0	\$0	0	0	0.0%
16 Cogen-Recip. Engine	53	384	\$132,898,631	\$48,517,277	2.74	4.67	12.0%
17 Cogen-Gas Turbine	3	4	\$40,751,200	\$4,746,669	8.59	1.4	6.0%
Subtotal (15, 16, 17)							
TOTALS	56	388	\$173,649,831	\$83,263,946	3.3	3.90	11.3%
		50163	\$564,669,348	\$119,603,357	4.7	2.81	9.5%

Table 10. Energy summary of ECOs.

	Total Energy Savings (MBtu/Yr)	Electricity Savings (MBtu/Yr)	Demand Savings (MBtu/Yr)	Gas Savings (MBtu/Yr)	Oil Savings (MBtu/Yr)	Coal Savings (MBtu/Yr)
FH Heating/Cooling						
1 FH High Efficiency Gas Furnace	0	0	0	0	0	0
2 FH Nominal Efficiency Gas Furnace	634892	-18233	0	653125	0	0
3 FH Gas-Engine Driven HP	-68483	561466	38303	-629949	0	0
Bldg HVAC						
4 Dessicant Cooling	-1298240	630011	111838	-1928251	0	0
Utilities/Central Plants						
5 Gas High Efficiency Boilers	1893955	0	0	1893955	0	0
6 Gas Nominal Efficiency Boilers	96	0	0	96	0	0
7 DF NG Chillers > 100 Tons	0	0	0	0	0	0
8 Gas-Engine Chillers > 100 Tons	-1132360	772080	75141	-1904440	0	0
9 DF NG Chillers 50-100 Tons	-10778	4208	553	-14986	0	0
10 Gas-Engine Chillers 50-100 Tons	-544929	425429	43504	-970358	0	0
11 DF NG Chillers 5-50 Tons	0	0	0	0	0	0
12 Gas-Engine Chillers 5-50 Tons	-304994	148152	15040	-453146	0	0
13 Gas-Engine Water Pump	-1742598	1032789	138211	-2775387	0	0
14 Gas-Engine Water Compressors	-9079	5383	581	-14462	0	0
Subtotal (1 thru 14)	-2,582,518	3,561,285	423,171	-6,143,803	0	0
15 Cogen-Fuel Cell	0	0	0	0	0	0
16 Cogen-Recip. Engine	-6275000	5738713	192000	-12013713	0	0
17 Cogen-Gas Turbine	-268205	597783	20000	-865988	0	0
Subtotal (15, 16, 17)	-6,543,205	6,336,496	212,000	-12,879,701	0	0
TOTALS	-9,125,723	9,897,781	635,171	-19,023,504	0	0

Table 11. Pollution summary of ECOs.

	Sox Abated (Tons)	NOx Abated (Tons)	Particulate Abated (Tons)	CO Abated (Tons)	CO ₂ Abated (Tons)	Hydrocarbons Abated (Tons)
FH Heating/Cooling						
1 FH Hi Efficiency Gas Furnace	0	0	0	0	0	0
2 FH Nom Efficiency Gas Furnace	-38	31	-1	10	33246	0
3 FH Gas Engine Driven HP	958	337	60	11	89755	3
Bldg HVAC						
4 Dessicant Cooling	1137	319	58	-9	28673	3
Utilities/Central Plants						
5 Gas High Efficiency Boilers	1	130	3	32	108903	1
6 Gas Nominal Efficiency Boilers	0	0	0	0	6	0
7 DF NG Chillers > 100 Tons	0	0	0	0	0	0
8 Gas-Engine Chillers > 100 Tons	1158	391	67	-5	51429	3
9 DF NG Chillers 50-100 Tons	11	3	1	0	488	0
10 Gas-Engine Chillers 50-100 Tons	623	198	33	-1	28767	1
11 DF NG Chillers 5-50 Tons	0	0	0	0	0	0
12 Gas-Engine Chillers 5-50 Tons	238	65	12	-2	4284	1
13 Gas-Engine Water Pump	1647	590	102	-6	79718	4
14 Gas-Engine Water Compressors	8	2	0	0	204	0
Subtotal (1 thru 14)	5,742	2,066	334	30	425,472	15
15 Cogen-Fuel Cell	0	0	0	0	0	0
16 Cogen-Recip. Engine	7545	2202	393	-5	342778	17
17 Cogen-Gas Turbine	1115	321	51	5	67731	2
Subtotal (15, 16, 17)	8,661	2,523	444	1	410,508	19
TOTALS	14,403	4,589	778	31	835,980	34

To provide an indication of the total (noncompeted) potential application for each of the cogeneration technologies, Table 12 shows the total number of opportunities listed in the REEP Simple Analysis (with less than a 10-year simple payback and a SIR greater than 1.25).

Highlights—Table 9 Financial Summary

The subtotal for gas technologies (without Cogeneration) indicates nearly 50,000 ECO opportunities with yearly savings of \$66M for the investment of \$391M; approximately a 6-year payback. Of the 50,000 opportunities, about three-fourths are family housing furnaces and heat pumps. The other ECOs with large numbers of opportunities are Desiccant Cooling (2730 opportunities) and High Efficiency Boilers (7457 opportunities).

The lowest simple paybacks among the non-Cogeneration ECOs were for Gas-Engine Chillers (5 to 50) tons, Gas-Engine Water Pumps, and Gas-Engine Air Compressors, all with paybacks slightly under 5 years.

Cogeneration-Reciprocal Engines exhibited the lowest payback (2.74 years) of all ECOs. This ECO, with only 384 opportunities, adds significantly to the savings and initial cost totals at the bottom of the table. In this competitive analysis (screening based on economics with no credit for pollution abatement), fuel cells were not selected for any sites. (Table 12 lists fuel cell opportunities.)

Highlights—Table 10 Energy Summary

For the non-Cogeneration ECOs, annual energy savings was negative 2 million MBtus/yr. Total energy consumption increased (even though energy costs were reduced as shown in the previous table). This is to be expected since many of the gas technologies produce cost savings by replacing expensive electrical consumption with cheaper gas energy consumption. Implementation of the non-Cogeneration ECOs is estimated to increase annual gas consumption by 6 million MBtus/year while reducing electrical consumption 3.5 million MBtus/year.

Table 12. REEP simple analysis (noncompeting) of ECOs—cogen only.

	Number of Opportunities	Initial Cost	Total Savings (\$/Yr)	Simple Payback (Yrs)	SIR Ratio
15 Cogen - fuel cell	112	\$82,386,326	\$12,527,296	6.6	1.84
16 Cogen - recip. engine	408	\$139,662,915	\$49,474,200	2.8	4.48
17 Cogen - gas turbine	41	\$451,402,000	\$72,432,514	6.2	2.24
Totals	561	\$673,451,241	\$134,434,010	5.0	2.65

Adding in the Cogeneration ECOs once again significantly changes the totals. Several of the savings subtotals for Cogeneration are several times larger than the subtotals for all other ECOs combined.

Table 11—Pollution Summary

This table provides estimates of abated pollution. Pollution values (for an assumed mix of electrical generation types for the region of the United States where the military installation is located) are used along with the REEP estimate of energy savings for each ECO to calculate abated pollution. Abated pollution from each site is summed to arrive at the abated pollution listed in the table for each ECO.

Table 12 Simple Analysis—Cogeneration Only

This table shows a (noncompetitive) financial summary for each of the three Cogeneration technologies. Only opportunities with less than a 10-year payback and greater than a 1.25 SIR were included. Fuel cell opportunities that were screened out by the other cogeneration technologies during the previous (competitive) analysis is estimated at 112 opportunities, \$82 million initial cost, and \$12 million per year savings with a 6.6 year payback. Due to continuing progress in economic viability of fuel cells, the REEP algorithm for fuel cells needs to be updated (and will be during this study). Also, the environmental advantages of fuel cells were not a consideration in the REEP screening process.

General Comments

The presentation of the REEP analysis to be included in the final report at the end of this project (after the advanced gas technology algorithms are developed and the existing algorithms are revised) will be given in greater detail in the final report for this study. Additional gas ECOs can be expected to change the REEP summary estimates for DOD-wide use of natural gas. More detailed breakouts of natural gas use within the DOD will also be included in the final report.

6 Summary and Conclusions

Of the total energy consumed by DOD (in FY94), 32 percent of the BBtus was supplied by natural gas. However, natural gas costs for the same time period were only 13.5 percent of the total energy costs. Thus, natural gas offers greater energy per dollar than some other energy supplies.

In FY94, approximately 25 percent of the natural gas consumed by the DOD was purchased through the Defense Fuel Supply Center purchasing program. The DFSC average cost of \$2.34 per dekatherm for natural gas (in FY95) is significantly lower than DOD's average cost of \$4.02 per dekatherm for all natural gas consumed (in FY94). According to DFSC calculations, DOD savings from the DFSC purchasing is \$72.1 million between October 1990 and July 1995 (pp 7, 8).

The DOD demonstrations of fuel cells, desiccant systems, and natural gas cooling are in-progress (Ch 4) at the following number of DOD sites:

Demonstration	Number of Sites
Natural Gas Cooling	18
Desiccant Cooling	11
Fuel Cells	12

Performance results and demonstration conclusions will be determined.

Candidate technologies (Chapter 3) will be considered along with others when determining the natural gas technologies to be included in the REEP program.

The preliminary REEP analysis (using gas ECOs already in REEP) estimated a potential annual savings (for noncogeneration technologies) at \$66 million. (Note that DOD purchased \$373 million of natural gas in FY94.) Cogeneration technologies produce large estimates of potential savings. However, it is doubtful that such large scale implementation of cogeneration would truly be practical.

The average cost per MBtu of natural gas is significantly lower than for electricity.

The DFSC purchasing program is providing significant savings in DOD natural gas costs. Reductions in the price of natural gas improve the economics of natural gas technologies compared to other fuel technologies. However, higher natural gas prices improve the economics of advanced technologies that use natural gas more efficiently.

The DOD demonstration programs have resulted in energy-saving equipment being installed at dozens of DOD sites with many more sites to be involved in FY96. Results from some of the earliest installed sites should be available in FY96.

Natural gas technologies will be identified and algorithms developed for inclusion in the REEP program. REEP will then be used to estimate DOD-wide energy and air emissions reduction potential. A more detailed presentation of the REEP analysis will be included in the final report at the end of this project (after the advanced gas technology algorithms are developed and the existing algorithms are revised). Additional gas ECOs can be expected to change the REEP summary estimates for DOD-wide use of natural gas. The final report will also include more detailed breakouts of natural gas use within the DOD.

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECG
ATTN: CECC-P
ATTN: CECC-R
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CECW-PR
ATTN: CEMP
ATTN: CEMP-E
ATTN: CEMP-C
ATTN: CEMP-M
ATTN: CEMP-R
ATTN: CERD-C
ATTN: CERD-ZA
ATTN: CERD-L
ATTN: CERD-M
ATTN: DAEN-ZC
ATTN: DAIM-FDP
ATTN: DASD(I)

CECPW 22310-3862
ATTN: CECPW-E
ATTN: CECPW-FT
ATTN: CECPW-ZC

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (11)

US Army Europe
ATTN: AEAEN-EH 09014
ATTN: AEAEN-ODCS 09014

29th Area Support Group
ATTN: AEUSG-K-E 09054

222d BSB Unit #23746
ATTN: AETV-BHR-E 09034

235th BSB Unit #28614
ATTN: AETV-WG-AM 09177

293d BSB Unit #29901
ATTN: AEUSG-MA-E 09086

409th Support Battalion (Base)
ATTN: AETTG-DPW 09114

412th Base Support Battalion 09630
ATTN: Unit 31401

221st Base Support Battalion
ATTN: Unit 29623 09096

CMTC Hohenfels 09173
ATTN: AETTH-SB-DPW

Mainz Germany 09185
ATTN: AETV-MNZ-E

21st Support Command
ATTN: DPW (8)

SETAF
ATTN: AESE-EN-D 09613
ATTN: AESE-EN 09630

Supreme Allied Command
ATTN: ACSGEB 09703
ATTN: SHIHB/ENGR 09705

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DPW 22186

USA TACOM 48397-5000
ATTN: AMSTA-XE

Defense Distribution Region East
ATTN: ASCE-WI 17070-5001

Defense Distribution Region West
ATTN: ASCW-WG 95296-0100

HQ XVIII Airborne Corps 28307
ATTN: AFZA-DPW-EE

US Army Materiel Command (AMC)
Alexandria, VA 22333-0001
ATTN: AMCEN-F
Installations: (20)

4th Infantry Div (MECH) 80913-5000
ATTN: AFZC-FE

FORSCOM
Forts Gillem & McPherson 30330
ATTN: FCEN
Installations: (20)

6th Infantry Division (Light)
ATTN: APVR-DE 99505
ATTN: APVR-WF-DE 99703

TRADOC
Fort Monroe 23651
ATTN: ATBO-G
Installations: (20)

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CETEC-ES 22315-3803
ATTN: Water Resources Support Ctr

USA Natick RD&E Center 01760
ATTN: STRNC-DT
ATTN: AMSSC-S-IMI

US Army Materials Tech Lab
ATTN: SLCMT-DPW 02172

USARPAC 96858
ATTN: DPW
ATTN: APEN-A

SHAPE 09705
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128
ATTN: ECJ4-EN

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

CEWES 39180
ATTN: Library

CECRL 03755
ATTN: Library

USA AMCOM
ATTN: Facilities Engr 21719
ATTN: AMSMC-EH 61299
ATTN: Facilities Engr (3) 85613

USAARMC 40121
ATTN: ATZIC-EHA

Military Traffic Mgmt Command
ATTN: MTEA-GB-EHP 07002
ATTN: MT-LOF 22041-5000
ATTN: MTE-SU-FE 28461
ATTN: MTW-IE 94626

Fort Leonard Wood 65473
ATTN: ATSE-DAC-LB (3)
ATTN: ATZT
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL
ATTN: Australian Liaison Office

Military Dist of WASH
Fort McNair
ATTN: ANEN-IS 20319

USA Engr Activity, Capital Area
ATTN: Library 22211

US Army ARDEC 07806-5000
ATTN: AMSTA-AR-IMC

Engr Societies Library
ATTN: Acquisitions 10017

U.S. EPA, Region V
ATTN: AFRC-ENIL-FE 60561

U.S. Army Environmental Center
ATTN: SFIM-AEC-NR 21010
ATTN: SFIM-AEC-CR 64152
ATTN: SFIM-AEC-SR 30335-6801
ATTN: AFIM-AEC-WR 80022-2108

Defense Nuclear Agency
ATTN: NADS 20305

Defense Logistics Agency
ATTN: MMDIS 22060-6221

National Guard Bureau 20310
ATTN: NGB-ARI

US Military Academy 10996
ATTN: MAEN-A
ATTN: Facilities Engineer
ATTN: Geography & Envir Engr

Naval Facilities Engr Command
ATTN: Facilities Engr Command (8)
ATTN: Division Offices (11)
ATTN: Public Works Center (8)
ATTN: Naval Constr Battalion Ctr 93043
ATTN: Naval Facil. Engr. Service Ctr 93043-4328

8th US Army Korea
ATTN: DPW (11)

USA Japan (USARJ)
ATTN: APAJ-EN-ES 96343
ATTN: HONSHU 96343
ATTN: DPW-Okinawa 96376

416th Engineer Command 60623
ATTN: Gibson USAR Ctr

US Army MEDCOM
ATTN: MCFA 78234-6000
Fitzsimons Army Medical Center 80045-5000
ATTN: MCHG-PW
Fort Detrick 21702-5000
ATTN: MCCHS-IS
Fort Sam Houston 78234-5000
ATTN: MCFA-PW
Walter Reed Army Medical Center 20007-5001
ATTN: MCHL-PW

Tyndall AFB 32403
ATTN: HQAFCESA/CES
ATTN: Engrg & Srvc Lab

USA TSARCOM 63120
ATTN: STSAS-F

American Public Works Assoc. 64104-1806

US Army CHPPM
ATTN: MCHB-DE 21010

US Gov't Printing Office 20401
ATTN: Rec Sec/Deposit Sec (2)

Natl Institute of Standards & Tech
ATTN: Library 20899

Defense General Supply Center
ATTN: DGSC-WI 23297-5000

Defense Construction Supply Center
ATTN: DCSC-WI 43216-5000

Defense Tech Info Center 22060-6218
ATTN: DTIC-O (2)